Compressibility Parameters of Peat Soils in Muthurajawela Region of Sri Lanka

T. Chenthan, S. Sharuja and M.C.M. Nasvi

Abstract: Peat is an extreme form of soft soil and its geotechnical properties cannot be determined so easily as it is waterlogged most of the time. Developing correlations among different properties of peat will enable study of geotechnical properties of peat. Hence, aim of this paper was to develop correlations among index properties, unconfined compressive strength (UCS) and compressibility parameters of some peat soils collected from Muthurajawela region, Sri Lanka. Fifteen disturbed and undisturbed samples were collected and index property, UCS and 1-D consolidation tests were conducted for all the samples. Seven correlations were developed based on the experimental results and it was noted that the correlations developed were consistent with similar correlations reported in the literature. The results show that the liquid limit (LL) of peat increases with organic content (OC) and water content (WC). In addition, both the specific gravity (G_s) and UCS values reduce with increase in OC value. When the WC increases, the UCS of peat tends to reduce as the water holding capacity of peat increases with the increase in WC. The compression index (C_c) reduces with the increase in LL and it is due to the increase in compressibility with the increase in LL. The findings of this study revealed that geotechnical engineers can refer to these correlations to study the preliminary behavior of peat soils in Muthurajawela region, where geotechnical data is not readily available.

Keywords: Compressibility, Correlation, Liquid limit, Peat

1.   Introduction

Peat is a soft soil made up of partially disintegrated plant and organic matter that have accumulated underwater and fossilized [1]. The decaying process of plants under acidic conditions without microbial process results in the formation of organic matter in peat [2]. Characteristics of peat are low bearing capacity, low specific gravity, medium to low permeability, high compressibility, high natural water content, high water holding capacity, high rate of creep and difficult accessibility [3, 4]. According to Bord and Mona [5], peatlands cover nearly 400 million hectares of the earth which is 3% of the total land surface area. In Sri Lanka, there are 25000 hectares of peatland [6]. Peat is classified into two major types, fibrous and amorphous. Von Post [7] further divided this into ten different ranges using Von Post scale system. In this system, peat is divided from H1 (completely fibrous peat) to H10 (completely amorphous peat) based on the degree of humification, water content, fiber content and botanical composition [8]. According to ASTM Standard D4427, standard peat classification is narrowed down to three classes, namely, fibric (fibrous: least decomposed with fiber content more than

67%), hemic (semi-fibrous: intermediate decomposed) and sapric (amorphous: most decomposed with fiber content less than 33%). As these are extremely soft soils, it is very difficult to determine their physical and geotechnical properties [3]. It is convenient to relate the basic geotechnical properties of peat to few of the easily determined index or physical properties of peat. Hence, development of correlations between different properties will be useful.

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Table 1 - Summary of previous studies on correlations among different parameters of peat

Reference	Types of peat and location	Developed correlations	Outcome of the study
[11]	All three types - fibric, hemic and sapric Queensland, Australia	$MDD = -0.0061\,WC + 1.5635$ $C_C = 0.0066LL - 0.1603$ $LL = 1.32\,WC + 8.614$ $C_C = 0.01\,WC - 0.07$	Formulae developed for these peats show that the physical and engineering properties of these peats fall within the range of those in tropical regions.
[3]	All three types - fibric, hemic and sapric Sarawak, Malaysia	$LL = -50.737\,MDD + 114.38$ $OMC = -52.53\,MDD + 100.62$ $FC = 0.762\,OC + 2.8509$ $LL = 0.2088\,OC + 59.982$ $OMC = 0.206\,OC + 45.04$ $MDD = -0.0041\,OC + 1.0691$ $G_S = -0.0078\,OC + 2.1605$	Developed correlations can be used to determine geotechnical properties of peat, especially when geotechnical data is not readily available.
[10]	Tropical organic and peat soils Johore, Perak, Sarawak and Selangor.	$OC(\%) = 0.0592\,WC(\%) + 54.34$ $OC(\%) = 0.1747\,LL(\%) + 20.377$ $G_S = 5.2636 \times (OC)^{-0.2848}$ $OC = 57.266 \times \gamma_b^{-4.9032}$	Four correlations were developed for peat soils and these correlations compare well with those published in the literature.
[9]	All three types - fibric, hemic and sapric West coast of Peninsular Malaysia	$LL = 0.3 + 3.0\,OC$ $\rho_d = 22.422\,(WC) - 0.804$ $G_S = 1/(0.362\,OC + 0.371)$	Correlations developed were consistent with similar correlations reported in the literature. For a given loading, tropical fibric peat will cause the highest settlements followed by hemic and sapricpeats.

WC - Water Content, C_C – Compression Index, LL – Liquid Limit, MDD – Maximum Dry Density, OMC – Optimum Moisture Content, FC – Fiber Content, OC – Organic Content, G_S – Specific Gravity, γ_b - Bulk Density, ρ_d – Dry Density.

Previous researchers [3, 9, 10, 11] have developed correlations among different properties of peat to derive the complex properties of peat from simple parameters. The summary of the findings of these studies are detailed in Table 1.

However, to date, there are very limited studies focusing on the correlation between different properties of peat soils in Sri Lanka. Hence, aim of this research was to develop correlations among index properties, strength and compressibility parameters of peat soils from Muthurajawela, Sri Lanka. The detailed experimental methodology and the results are discussed in the following sections.

2. Materials and Methods

2.1 Materials

Peat samples for the experimental analysis were collected from two different locations on both sides of Colombo - Katunayake Expressway (CKE) located in the Western Province of Sri Lanka. The depth of sampling was about one foot from the ground surface and the ground water table was found to be at the ground surface. Prior to sampling, surface vegetation was removed to facilitate sampling. Figure 1 shows the location of the sampling along the CKE alignment. These two sampling locations were chosen to cover two representative locations of Muthurajawela region.
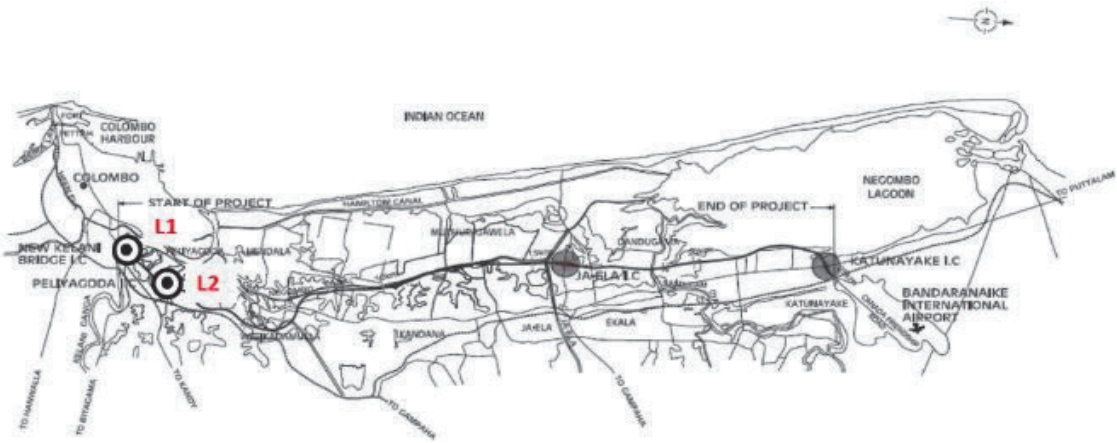
Figure 1 – Sampling locations (L1 and L2) along the CKE alignment

(a)   (b)   (c)

Figure 2 – Sampling tube used and the sampling procedure: (a) Tapered PVC tube; (b) PVC tube driving for sampling; (c) Sample extraction

2.2   Experimental Methodology

Fifteen undisturbed samples, S1 to S15, were collected from both locations using PVC tubes of 150 mm diameter and 400 mm height. One end of the PVC tube was tapered to sharpen the edges to facilitate sampling. Figure 2 shows the tapered PVC tube used and the sampling procedure. Undisturbed samples were waxed immediately after extraction from the field to retain the in-situ moisture conditions of the samples. From each sampling location, disturbed samples were also collected for the determination of index properties.

Index Property tests including moisture content (BS 1377: Part 2: 1990), Atterberg limits (BS 1377: Part 2: 1990), Loss on ignition (BS 1377: Part 3: 1990) and specific gravity (BS 1377: Part 2: 1990) were conducted for all the peat samples to determine the moisture content, consistency limits, organic content and specific gravity, respectively. Unconfined compressive strength (UCS) tests were conducted according to BS 1377: Part 7: 1990 to
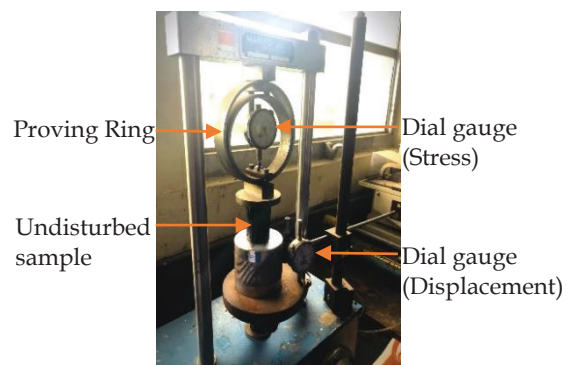
determine the compressive strength of peat samples.

Figure 3 - UCS setup used for the testing

Undisturbed peat samples of 38 mm in diameter and 76 mm in height were used for UCS testing and the UCS apparatus available at Geotechnical Engineering Laboratory, Department of Civil Engineering, University of Peradeniya (Figure 3) was used for the testing. A constant strain-controlled loading rate of 0.7 ± 0.1 mm/min was maintained throughout the test. For each test, three samples were tested to

ensure reproducibility. One dimensional (1-D) consolidation tests were conducted to measure the compressibility parameters of peat samples according to BS 1377: Part 5: 1990. Undisturbed peat samples of 75 mm diameter and 20 mm height were used for the 1-D consolidation tests. Samples were saturated for 24 hours in the cell before commencing the tests to ensure full saturation of the samples. A series of normal loads of 20, 40, 80 and 160 kPa were applied. Each load was kept for a period of 24 hours and the dial gauge readings were recorded with time.

3. Results and Discussions

3.1 Geotechnical Engineering Properties of Peat Samples

Figure 4 shows the void ratio vs logarithmic effective stress (e – log σ') plots for sample numbers 1, 5, 10 and 15. From Figure 4, the compression index (C_c) values of the samples were calculated. Table 2 shows the overall results of index properties, Water Content (*WC*), Liquid Limit (*LL*), Specific Gravity (*G_S*) and Organic Content *(OC)*], *UCS* and C_c of all the fifteen tested peat samples. Based on Table 2, water content of Muthurajawela peat varies in the range from 12.2% to 164.8%, liquid limit from 41.6% to 96.2%, organic content from

4.3% to 32.9% and specific gravity from 1.73 to 2.59. Based on the literature on peat soils [2, 3, 9, 12, 13], water content varies from 140% to 2000%, liquid limit varies from 39% to 550%, specific gravity varies from 0.95 to 2.66, and organic content varies from 0% to 100%. Hence, the index property results are comparable with those reported for peat in the literature. Engineering properties reported in Table 2 were used to develop the correlations for peat.

3.2 Correlation among Index Properties, *UCS* and Compression Index of Peat

Correlations were developed among index properties, *UCS* and C_c and the developed correlations were compared with similar correlations reported in the literature for peat. Figure 5 shows the plot of Liquid Limit (*LL*) with Organic Content (*OC*) and similar plots from literature [3, 9, 14, 15] are also plotted for comparison. The relationship obtained for *LL* vs *OC* is given in Equation (1). The coefficient of correlation (R^2) for the developed correlation is 0.82 indicating a good correlation. Experimental results plotted, closely fit with similar plots reported in the literature as shown in Figure 5.
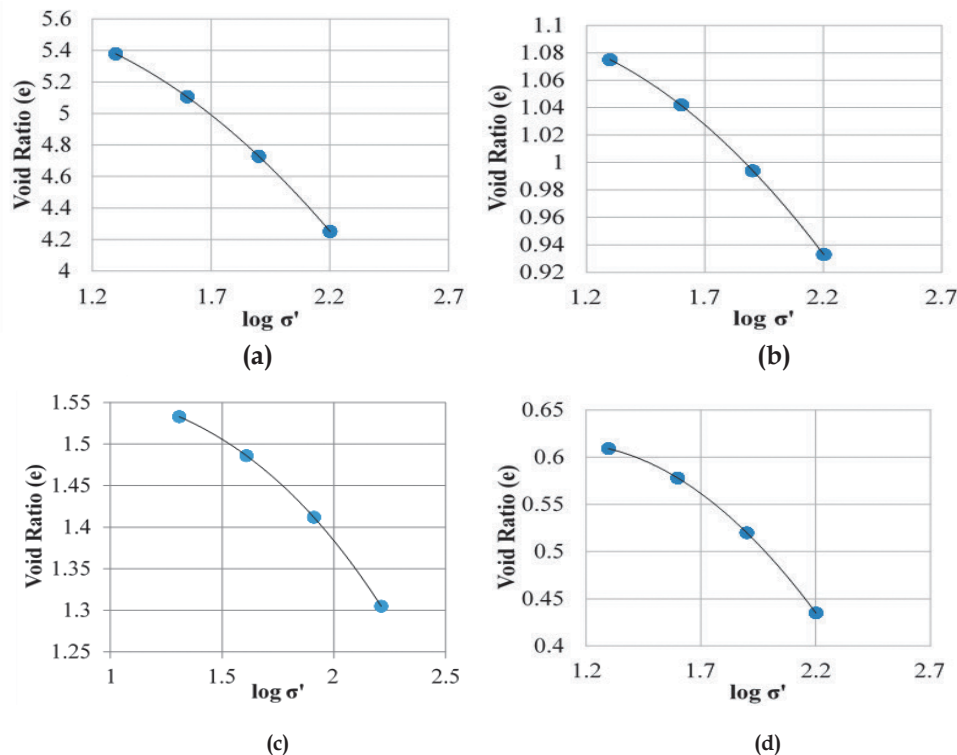

Figure 4 - e-log σ' plots (a) Sample No.1 (b) Sample No.5, (c) Sample No.10 and (d) Sample No.15

Table 2 - Index properties, UCS and C_C values of all the tested peat samples

Sample No.	WC (%)	LL (%)	G_S	OC (%)	UCS (kPa)	C_C
1	54.5	59.0	2.36	4.30	15.2	1.875
2	12.2	73.9	2.31	27.39	18.2	0.670
3	116.4	70.7	1.73	29.39	22.7	0.240
4	126	67.9	1.96	27.36	30.1	0.730
5	111.2	96.2	2.05	25.85	9.8	0.235
6	83.9	74.8	2.03	26.17	19.4	0.150
7	59.6	62.8	2.39	18.20	9.2	0.380
8	115.9	70.7	2.06	32.90	11.6	1.200
9	139.4	55.2	2.10	9.10	40.1	0.330
10	38.7	42.8	2.43	12.02	22.9	0.300
11	155.4	69.6	2.22	31.83	23.8	0.190
12	75.8	43.8	2.45	16.12	38.0	0.180
13	36.5	41.6	2.59	9.93	49.8	0.330
14	42.0	44.3	2.02	22.85	33.8	0.370
15	164.8	58.6	2.27	21.40	24.1	0.270

The results show that *LL* increases with *OC*. It is widely accepted that the available water holding capacity of soil increases with the organic matter content. Along with the increase in *OC*, the water holding capacity of the peat soil becomes higher [9,10] leading to increase in the *LL* values.

$$LL(\%) = 1.4795 \, OC(\%) + 27.572 \qquad ...(1)$$

Figure 6 shows the correlation developed between *LL* and water content (*WC*), and Equation (2) gives the developed correlation. It can be seen from Figure 6 that the developed correlation matches well with similar correlations reported in the literature [3, 10, 11]. Higher natural water content indicates the higher water holding capacity of peat soil. Higher water holding capacity of peat soil leads to higher *LL*. Although *LL* of Muthurajawela peat increases with increase in *WC* (Figure 6), it does not show a drastic increase as reported in previous studies [10, 11].

$$LL(\%) = 13.703 \ln(WC(\%)) - 2.7103 \quad ...(2)$$

The relationship between *OC* and WC is shown in Figure 7. According to Figure 7, the trend of the relationship compares well with the existing correlations on *OC* vs *WC* reported in the literature [3, 10, 15]. The developed correlation between *OC* and *WC* is given in Equation (3). An increase in *OC* of peat soil increases its water holding capacity. Because of the higher *OC*, the natural *WC* of peat increases [3, 10]. Muthurajawela peat shows lower *OC* values compared to peat soils reported in the literature [3, 10, 15] (Figure 7).

$$OC(\%) = 0.1933 \, WC(\%) + 5.2101 \qquad ...(3)$$

The specific gravity (*G_s*) of Sri Lankan peat was found to be in the range of 1.73 to 2.59. Equation (4) and Figure 8 show the relationship between *G_s* with *OC*. Based on Figure 8, it can be seen that the correlation developed in the present study matches well with similar correlations reported in the literature. As high *OC* implies more air voids, increase in *OC* greatly affects the *G_s* of peat soil. Therefore, *G_s* reduces with the increase in *OC*. It can be seen that Muthurajawela peats show a greater reduction in *G_s* with the increase in OC compared to the peats reported in the literature [3, 10, 15].

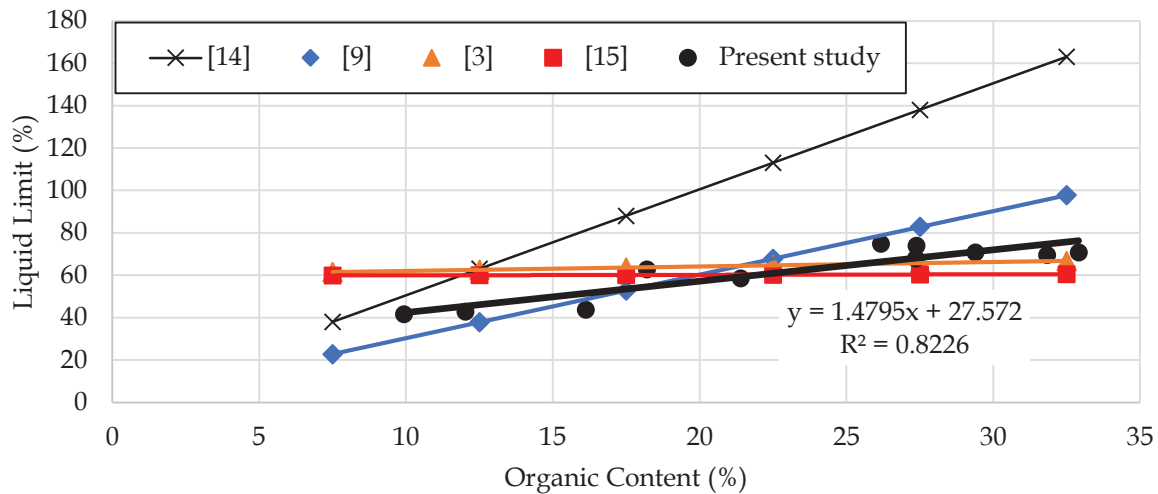$$G_S = -0.032 \, OC(\%) + 2.8846 \qquad ...(4)$$

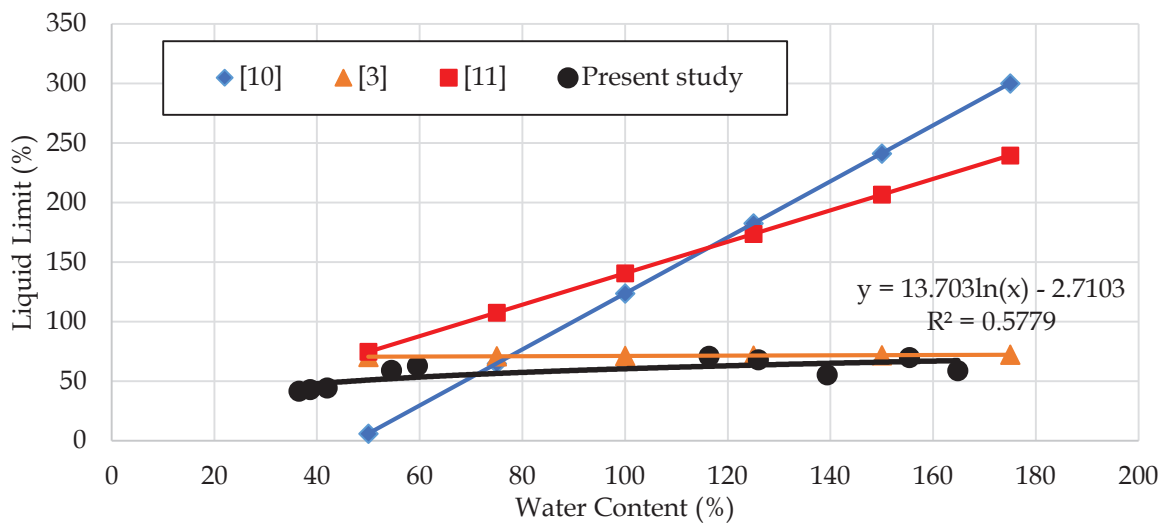**Figure 5 - Correlation between liquid limit and organic content**

The equation shown on Figure 5:

$$y = 1.4795x + 27.572$$
$$R^2 = 0.8226$$

Figure 6 - Correlation between liquid limit and water content

The equation shown on Figure 6:

$$y = 13.703\ln(x) - 2.7103$$
$$R^2 = 0.5779$$
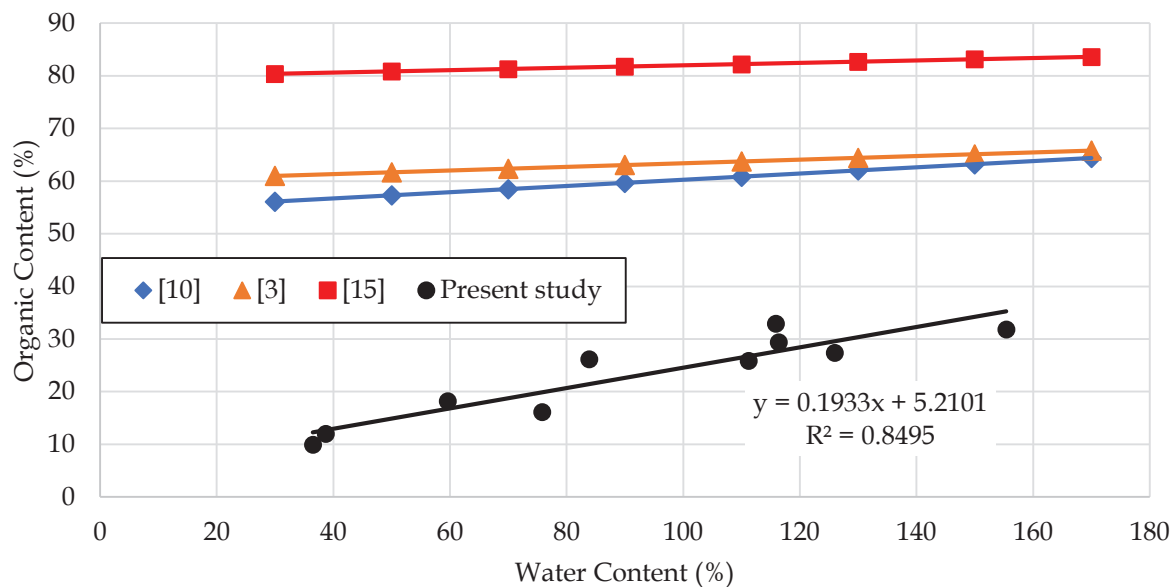
Figure 7 - Correlation between organic content and water content

The equation shown on Figure 7:

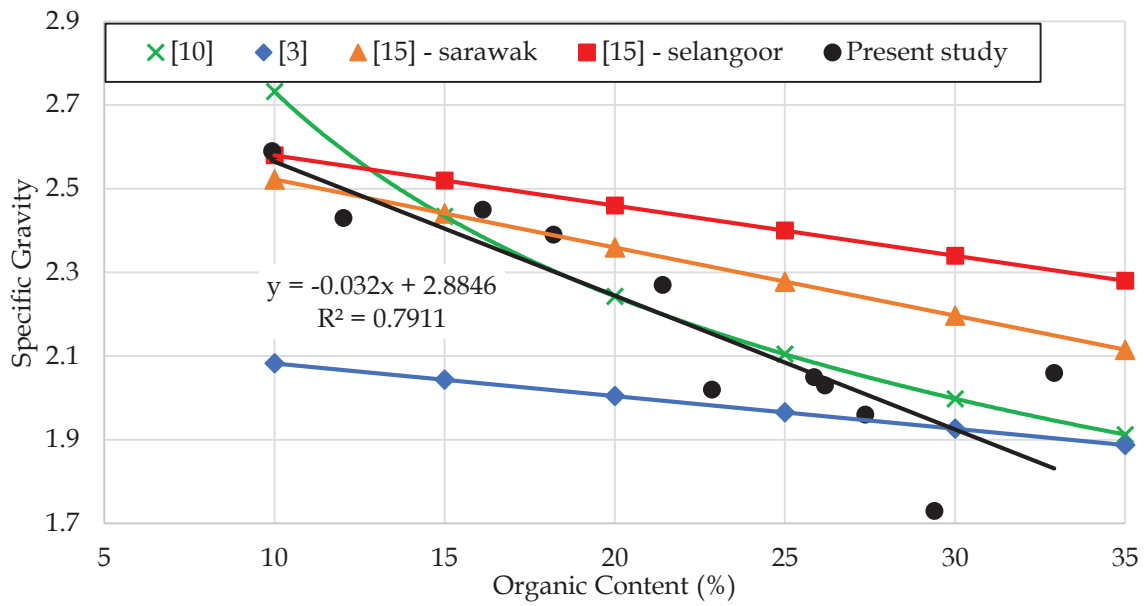$$y = 0.1933x + 5.2101$$
$$R^2 = 0.8495$$

Figure 8 - Correlation between specific gravity and organic content

The correlation developed between the Unconfined Compressive Strength (*UCS*) and *LL* is shown in Figure 9 and the developed correlation is given in Equation (5). According to Figure 9, increase in *LL* results in a reduction in UCS value and it is because the rises in *LL* increase the water holding capacity. As the water content increases effective stress reduces, leading to reduced *UCS* values.

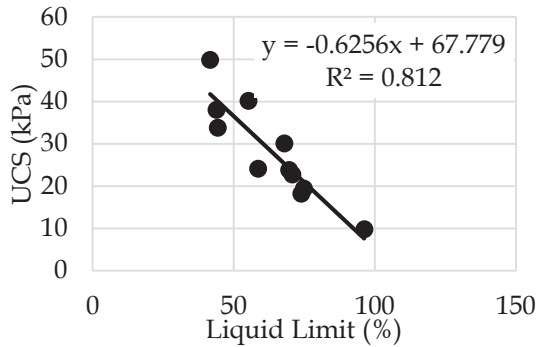$$UCS(kPa) = -0.6256 \, LL(\%) + 67.779 \quad …(5)$$

Figure 9 - Correlation between unconfined compressive strength and liquid limit

Figure 10 shows the variation of *UCS* with *OC* and the developed correlation is given in Equation (6). There are no reported correlations in the literature between *UCS* and *OC* for peat soil. The result shows that *UCS* decreases with an increase in *OC*. An increase in *OC* in peat soil increases the water holding capacity of the peat soil leading to an increase in *WC*. The *UCS* of peat reduces as the WC increases.

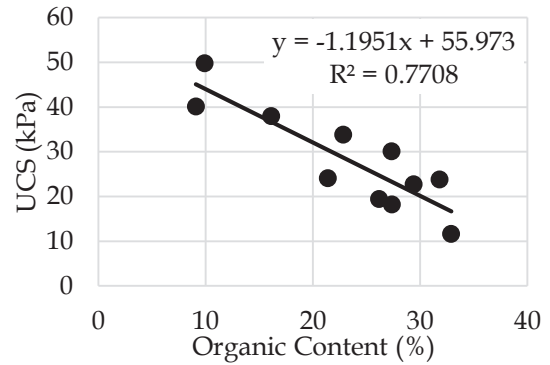$$UCS(kPa) = -1.1951 \, OC(\%) + 55.973 \quad …(6)$$

Figure 10 - Correlation between unconfined compression strength and organic content

Figure 11 shows the relationship between the compression index (C_c) and *LL* and the developed correlation is given in Equation (7). The developed correlation is consistent with similar correlations reported in the literature [11, 14, 16]. As *LL* increases, the water holding capacity of peat increases. Higher water holding capacity leads to higher compression leading to increase in C_c values. The C_c values of peats in the present study fall within the range of C_c values reported in the literature.

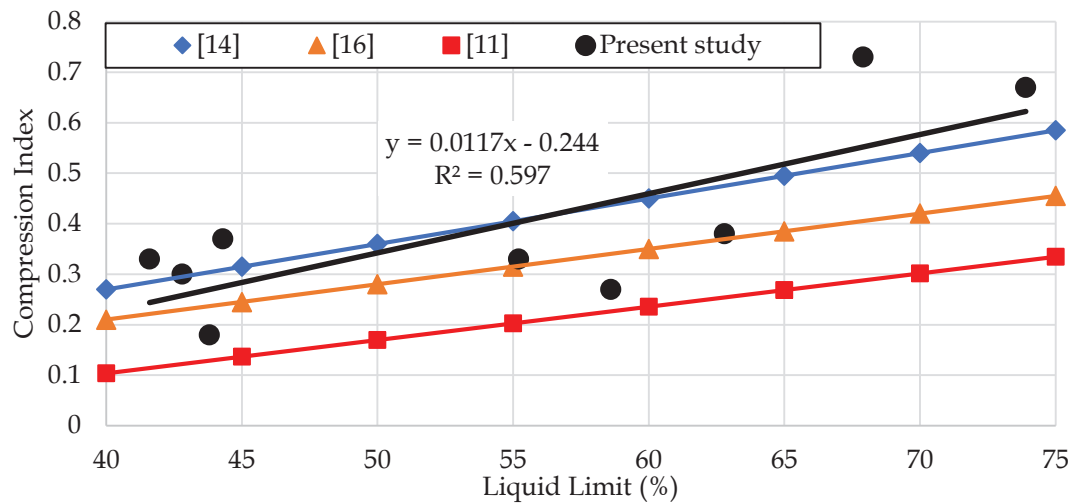$$C_c = 0.0117 \, LL(\%) + 0.244 \quad\quad …(7)$$

Figure 11 - Correlation between Compression Index and Liquid limit

Summary of the developed correlations and similar correlations reported in the literature are compared in Table 3.

Table 3 - Comparison of developed correlations in literature

Developed Correlation	Similar correlations from literature	
$LL\,(\%) = 1.4795\,OC(\%) + 27.572$	$OC = 59.725 e^{0.00038(LL\,(\%))}$	[15]
	$LL\,(\%) = 0.2088\,OC(\%) + 59.982$	[3]
	$LL\,(\%) = 5\,OC(\%) + 0.5$	[14]
	$LL\,(\%) = 3\,OC(\%) + 0.3$	[9]
$LL\,(\%) = 13.703\ln(WC(\%)) - 2.7103$	$LL\,(\%) = 2.353\,WC(\%) - 111.76$	[10]
	$LL\,(\%) = 1.32\,WC(\%) + 8.614$	[11]
	$LL\,(\%) = 0.0133 WC(\%) + 69.821$	[3]
$OC\,(\%) = 0.1933 WC(\%) + 5.2101$	$OC(\%) = 0.0231\,WC(\%) + 79.666$	[15]
	$OC\,(\%) = 0.0342\,WC(\%) + 59.983$	[3]
	$OC\,(\%) = 0.0592\,WC(\%) + 54.34$	[10]
$Gs = -0.032OC(\%) + 2.8846$	$G_S = -0.016281\,OC(\%) + 2.685$ (Sarawak)	[15]
	$G_S = -0.012\,OC(\%) + 2.7$ (Selangoor)	[15]
	$G_S = -0.0078\,OC(\%) + 2.1605$	[3]
	$G_S = 5.2636\,OC(\%)^{-0.2848}$	[10]
$UCS(\text{kPa}) = -1.1951OC(\%) + 55.973$	No reported correlations in literature between UCS and OC	
$UCS(kPa) = -0.6256LL(\%) + 67.779$	No reported correlations in literature between UCS and LL	
$C_C = 0.0117LL(\%) - 0.244$	$C_C = 0.0066\,LL(\%) - 0.1603$	[11]
	$C_C = 0.009\,(LL(\%) - 10)$	[14]
	$C_C = 0.007\,(LL(\%) - 10)$	[16]

3.3 Real Field Applications of the Proposed Correlations

Due to the high water content levels and the soft nature of peat soils, it is difficult to determine their physical and geotechnical properties. In addition, there is no proper geotechnical database on the properties of Sri Lankan peat. Hence, the developed correlations between index properties, strength and consolidation parameters of Sri Lankan peat will help the geotechnical engineers in design and construction in this region. Estimation of complex properties (UCS, C_c) using few index properties (LL, OC) will be very useful as the sampling and testing of these softs soils are not easy and consume a lot of time. Estimation of consolidation settlement requires C_C and a quick estimation of C_C can be done by knowing the LL. With the estimated C_C, consolidation settlements can be estimated rapidly to get some idea about the expected primary consolidation settlement before detailed assessments. Proposing ground improvement techniques is much easier when there are correlations among different properties of peat. These correlations can be used to determine various engineering properties of peat and, based on the results, the type of peat can be predicted. Hence, suitable ground improvement techniques for the given peat type can be proposed based on the results.

4. Conclusions

Major aim of this study was to develop correlations among index properties, unconfined compressive strength and compressibility parameters of peat soils in the Muthurajawela region located in the western coast of Sri Lanka. Index property tests (water content, loss on ignition, Atterberg limits and specific gravity), unconfined compressive strength (UCS) and 1-D consolidation test were performed for fifteen peat samples extracted from two different locations along the Colombo Katunayake Expressway (CKE). Based on the experimental outcomes, the following conclusions were drawn:

- Seven correlations were developed among liquid limit *(LL)*, water content *(WC)*, organic content *(OC)*, specific gravity *(G_s)*, Unconfined Compressive Strength (*UCS)* and compression index *(C_c)* and the developed correlations were compared with existing correlations reported in the literature. The correlations developed were

consistent with similar correlations reported in the literature.

- LL of peat soil increases with both OC and WC. An increase in the OC increases the water holding capacity of peat leading to an increase in LL.

- G_s value of peat decreases with OC and it is because peat with higher OC has a greater proportion of voids leading to reduced G_s values.

- UCS of peat reduces with both LL and OC and it is because the water-holding capacity of soil increases with increase in both LL and OC. This leads to reduce the strength with the increase in both LL and OC.

- C_c of peat increases with increase in LL and it is due to the increased water-holding capacity of peat with increase in LL. An increase in water-holding capacity makes the peat to be more compressible leading to increased C_c values.

- On the whole, findings of this study will be useful for geotechnical engineers in the following ways: (i) Geotechnical properties of peat can be better understood; (ii) Complex geotechnical parameters can be obtained using simply determined parameters; (iii) Approximate consolidation settlement can be predicted quickly; and (iv) Suitable ground improvement techniques can be predicted based on the geotechnical properties obtained from these correlations.

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